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2.3 EVAPOTRANSPIRATION

The calculation of evapotranspiration (ET) in the South Florida Water Management Model (SFWMM) is based on reference crop potential ET which is adjusted according to crop type, available soil moisture content, and location of the water table. Algorithms used to calculate actual evapotranspiration vary geographically because of different data availability, calibration approaches and varying physical and operational characteristics of different areas within the model domain. For Lake Okeechobee, the pan evaporation method is used to calculate open water and marsh zone ET. In the Everglades Agricultural Area (EAA), total ET is the sum of its components from the saturated, unsaturated and open water zones. In non-irrigated areas such as the Everglades, the unsaturated zone is not modeled and total ET is calculated as the sum of open water evaporation and saturated zone (water table) ET. Finally, in irrigated areas within the Lower East Coast (LEC), an application of Agricultural Field-Scale Irrigation Requirements Simulation Model (AFSIRS) was used to calculate ET and recharge while saturated and open water ET are calculated as described below.

2.3.1 Determination of Potential Evapotranspiration

In the SFWMM, predicted evapotranspiration is calculated by spatial interpolation of the reference or potential evapotranspiration between the sites, and by the application of landscape-specific crop coefficients that are a function of water depth. These landscape-specific crop coefficients are obtained by calibration as part of the SFWMM calibration/verification effort. Several potential methods for estimating potential or reference evapotranspiration for use in these regional long-term continuous simulation models were examined. The selected method for potential evapotranspiration estimation is presented here.

The SFWMD Simple Method (Abtew, 1996; Equation 2.3.1.1) was selected to provide estimates of long-term historical (1965-2000) *wet marsh potential ET* for long-term hydrological modeling

$$ET_p = \frac{K_1 R_s}{\lambda} \quad (2.3.1.1)$$

where:

- ET_p = wet marsh potential evapotranspiration [mm dd⁻¹];
- K₁ = coefficient (0.53 for mixed marsh, open water and shallow lakes);
- R_s = solar radiation received at the land surface [MJ m⁻² d⁻¹]; and
- λ = latent heat of evaporation [MJ kg⁻¹].

It is important to keep in mind that due to the difference in roughness characteristics between marsh and reference grass surfaces, the crop coefficients developed with respect to a grass reference ET may need to be modified for use with wet marsh potential ET. Due to the scarcity of solar radiation and cloud cover data, the self-calibrating K_r method (Hargreaves and Samani, 1982; Allen, 1997; Equation 2.3.1.2) was chosen for estimating solar radiation (R_s) for potential ET estimation since it depends on a single parameter with low spatial variability.

$$R_s = \tau R_a = K_r (T_{\max} - T_{\min})^{0.5} R_a \quad (2.3.1.2)$$

where:

R_s = solar radiation received at land surface [$\text{MJ m}^{-2} \text{d}^{-1}$];

τ = atmospheric transmissivity;

K_r = empirical coefficient;

T_{\max} = mean daily maximum temperature over the period of interest [$^{\circ}\text{C}$];

T_{\min} = mean daily minimum temperature over the period of interest [$^{\circ}\text{C}$]; and

R_a = extraterrestrial solar radiation [$\text{MJ m}^{-2} \text{d}^{-1}$].

Extraterrestrial solar radiation (R_a) is calculated from latitude and time of year by integrating the instantaneous radiation intensity at the outer atmosphere from sunrise to sunset:

$$R_a = \frac{(24)(60)}{\pi} G_{sc} d_r (\omega_s \sin \varphi \sin \delta + \cos \varphi \cos \delta \sin \omega_s) \quad (2.3.1.3)$$

where:

R_a = extraterrestrial solar radiation [$\text{MJ m}^{-2} \text{d}^{-1}$];

G_{sc} = solar constant = 0.8202 (Duffie and Beckman, 1991) [$\text{MJ m}^{-2} \text{min}^{-1}$];

d_r = relative distance from the sun to the Earth;

ω_s = sunset hour angle [rad];

φ = station latitude [rad]; and

δ = declination of the sun [rad].

The relative distance from the sun to the Earth (d_r), the declination of the sun (δ) and sunset hour angle (ω_s) are given by:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi J}{365}\right) \quad (2.3.1.4)$$

$$\delta = 0.409 \sin\left(\frac{2\pi J}{365} - 1.39\right) \quad (2.3.1.5)$$

$$\omega_s = \arccos(\tan \varphi \tan \delta) \quad (2.3.1.6)$$

where:

J = Julian day of the year.

The K_r method was applied at 17 National Oceanic and Atmospheric Administration (NOAA) stations with long-term (1965-2000) daily temperature data to provide long-term estimates of R_s for hydrologic modeling. For Lake Okeechobee, the average estimated R_s at Canal Point, Moore Haven and Belle Glade data collection stations was used. The NOAA temperature data was thoroughly checked and patched to correct systematic errors, trends and missing values with the purpose of producing the best possible temperature dataset for R_s and ET estimation.

In order to guarantee reasonable estimates, the following two constraints were incorporated into the R_s estimation:

- A constant upper bound for the transmissivity is set to 0.75 across South Florida (i.e. clear-sky transmissivity defined as 75% of the extraterrestrial solar radiation; Smith, 1991).
- A lower bound for the transmissivity is set at 10% of the clear-sky transmissivity.

For each NOAA station, the K_r was selected so that the long-term average annual wet marsh potential ET estimated by the Simple method (Equation 2.3.1.1) matched an expected north to south gradient (Visser and Hughes, 1969). Figure 2.3.1.1 shows that the selected K_r values do not vary significantly from station to station with generally lower values occurring in the interior (e.g. minimum value of 0.154 at Devil's Garden) and higher values near the coast (e.g. maximum of 0.210 at Miami International Airport). In general, the selected K_r values agree with Hargreaves' (1994) recommendation of using $K_r=0.16$ for interior regions and $K_r=0.19$ for coastal regions. Annual time series and summary statistics of wet marsh potential evapotranspiration estimated at 17 NOAA stations and Lake Okeechobee are presented in Table 2.3.1.1.

The TIN method was selected for spatially-interpolating the wet marsh potential ET across a 2-mile by 2-mile super grid covering most of South Florida (Figure 2.3.1.2). Unlike rainfall stations, there is a scarcity of stations where wet marsh potential ET was estimated. Furthermore, ET is likely to be less localized than rainfall. Therefore, it was appropriate to apply the TIN methodology which resulted in a smoother spatial variation of potential ET.

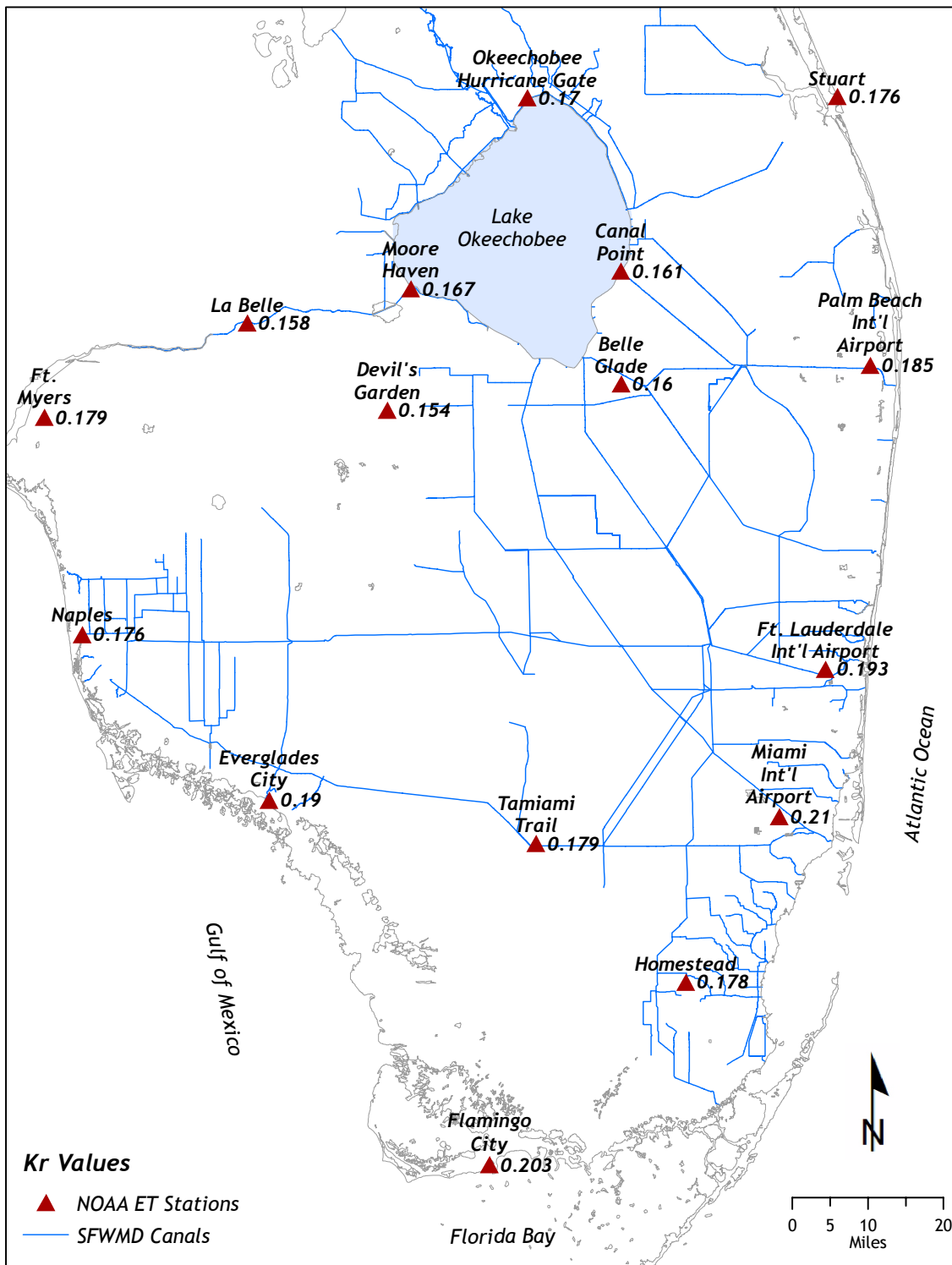


Figure 2.3.1.1 Selected K_r Values for 17 National Oceanic and Atmospheric Administration Stations with Long-Term Daily Temperature Data

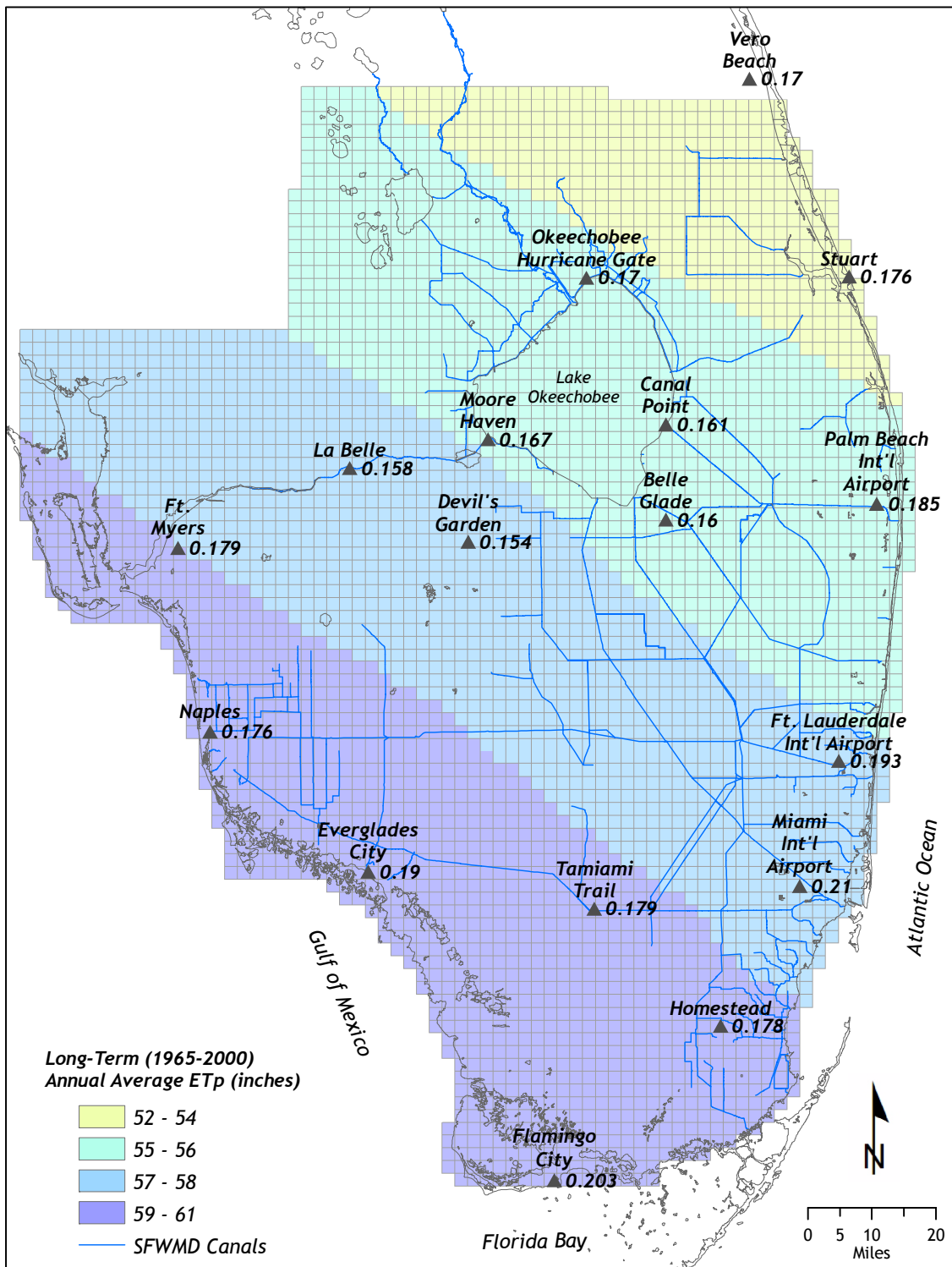


Figure 2.3.1.2 Estimated Annual Average Wet Marsh Potential Evapotranspiration for a 2-mile x 2-mile Super-Grid which Includes the South Florida Water Management Model and Natural System Model Grids

Table 2.3.1.1 Annual Time Series and Summary Statistics of Wet Marsh Potential Evapotranspiration Estimated at 17 National Oceanic and Atmospheric Administration Stations Plus Lake Okeechobee

Year	LOK	La Belle	Devils Garden	Ft Myers	Naples	Everglades City	Flamingo	Homestead	Tamiami Trail	Miami	Ft Lauderdale	WPBIA	Canal Point	Belle Glade	Moore Haven	Okeechobee Hurr. Gate	Stuart	Vero Beach
Kr	N/A	0.158	0.154	0.179	0.176	0.190	0.203	0.178	0.179	0.210	0.193	0.185	0.161	0.160	0.167	0.170	0.176	0.170
1965	55.27	56.57	54.88	57.96	59.53	62.05	59.58	61.53	60.80	57.74	58.76	55.87	55.16	56.25	54.39	56.14	52.66	52.69
1966	52.74	54.92	53.90	56.94	57.94	60.51	56.77	58.36	56.16	56.85	57.67	53.80	53.13	53.83	51.25	54.77	51.78	52.01
1967	56.58	58.40	55.75	56.46	59.36	60.73	58.52	60.24	63.63	54.76	57.70	57.05	56.86	56.49	56.38	53.21	54.85	54.47
1968	54.57	57.37	54.53	57.70	58.36	60.22	57.89	59.07	59.78	55.59	58.36	56.27	54.31	54.79	54.61	53.97	54.87	53.17
1969	53.03	56.72	53.54	53.86	58.11	60.46	58.24	57.29	56.65	58.07	57.37	53.63	53.77	53.04	52.30	50.78	52.73	50.73
1970	54.75	58.85	55.27	55.86	60.22	58.52	58.93	59.37	53.54	56.73	57.92	54.79	55.18	53.65	55.41	51.84	55.93	52.94
1971	56.90	61.77	58.13	57.34	61.43	60.25	61.70	61.54	61.22	58.62	60.41	57.96	56.89	55.59	58.21	56.08	53.13	53.75
1972	55.60	59.76	56.42	59.32	60.88	58.41	59.34	58.77	58.83	55.98	58.19	54.90	54.34	54.04	58.41	55.23	52.56	52.61
1973	55.71	57.06	56.50	59.23	61.91	60.27	60.01	58.02	59.57	54.62	57.74	54.32	55.03	54.40	57.70	55.47	52.47	51.50
1974	55.95	58.07	57.64	59.90	62.95	60.58	57.60	59.85	60.10	57.24	57.72	53.94	55.66	54.77	57.43	56.04	55.65	53.09
1975	56.29	58.97	56.33	59.61	62.70	58.42	60.72	59.97	59.04	57.45	56.73	54.92	56.09	55.04	57.75	55.73	55.75	54.59
1976	55.38	57.73	57.58	59.14	62.31	60.21	62.08	58.09	56.12	56.63	55.27	54.38	54.92	53.90	57.32	53.63	56.06	54.08
1977	55.66	58.69	56.96	57.89	61.44	59.61	62.38	58.36	57.40	56.14	55.13	55.03	54.66	54.54	57.77	52.47	53.77	53.75
1978	53.65	58.38	53.99	57.57	59.82	59.58	61.30	57.30	55.98	54.80	56.13	55.06	53.85	52.65	54.45	52.95	53.31	53.72
1979	53.84	56.35	54.59	57.93	60.48	57.97	60.21	57.48	58.29	52.95	56.48	54.57	54.01	52.68	54.83	52.07	50.32	52.24
1980	55.30	57.67	55.35	58.56	60.36	58.80	61.83	59.01	59.75	55.86	57.58	57.78	55.20	53.85	56.84	54.41	54.37	54.06
1981	57.27	59.41	59.09	60.05	63.16	60.43	63.72	59.75	62.67	59.88	59.25	57.32	55.96	54.93	60.92	57.32	55.32	55.58
1982	54.03	55.33	52.69	56.76	60.70	57.69	60.75	58.33	60.47	56.36	56.56	50.83	53.31	53.18	55.59	55.91	51.90	50.85
1983	54.50	54.48	53.74	54.26	59.79	57.51	60.58	58.16	57.95	59.52	58.15	52.08	53.43	55.99	54.09	55.69	51.86	52.57
1984	54.58	55.53	54.30	56.73	58.12	60.35	61.41	62.29	56.93	59.23	55.56	52.67	54.25	55.10	54.40	55.00	54.78	50.41
1985	56.16	56.87	59.21	58.30	57.75	60.30	62.75	57.98	61.93	61.09	57.03	54.34	54.33	56.71	57.44	54.11	54.18	51.41
1986	55.96	56.85	55.05	59.85	58.34	61.27	63.42	57.82	57.20	60.40	55.53	54.59	54.87	56.89	56.11	55.00	53.76	54.64
1987	55.65	55.08	55.81	58.74	56.96	60.21	62.85	56.81	56.57	59.10	54.64	53.79	54.00	56.82	56.12	55.25	53.09	53.13
1988	55.65	56.33	59.00	60.61	58.36	63.59	58.07	55.40	57.99	58.80	55.10	53.90	54.60	56.51	55.83	55.00	52.60	52.85
1989	57.94	57.56	59.25	61.41	58.70	56.99	57.89	58.52	64.46	60.38	56.12	55.87	57.08	57.80	58.93	57.62	54.25	54.85
1990	57.10	56.37	57.11	60.83	58.71	56.90	61.55	58.10	63.73	58.41	54.95	54.20	56.64	57.36	57.30	51.22	51.26	52.09

Table 2.3.1.1 (cont) Annual Time Series and Summary Statistics of Wet Marsh Potential Evapotranspiration Estimated at 17 NOAA Stations plus Lake Okeechobee

Year	LOK	La Belle	Devils Garden	Ft Myers	Haples	Everglades City	Flamingo	Homestead	Tamiami Trail	Miami	Ft Lauderdale	WPBIA	Canal Point	Belle Glade	Moore Haven	Okeechobee Hurr. Gate	Stuart	Vero Beach
Kr	N/A	0.158	0.154	0.179	0.176	0.190	0.203	0.178	0.179	0.210	0.193	0.185	0.161	0.160	0.167	0.170	0.176	0.170
1991	55.58	55.61	57.80	58.12	56.90	59.62	61.47	57.95	59.45	57.54	52.72	53.19	54.81	56.37	55.55	50.10	52.16	51.55
1992	55.38	54.66	57.45	58.23	57.35	57.69	61.20	59.44	59.79	58.21	54.26	54.71	54.61	56.23	55.30	52.79	52.86	53.44
1993	55.87	54.35	57.63	57.82	57.95	60.45	61.48	58.35	54.22	57.55	54.17	53.73	54.58	57.41	55.63	55.49	52.47	53.34
1994	53.90	56.24	58.28	57.11	55.85	59.39	60.74	59.24	56.36	55.41	51.19	54.97	53.30	55.05	53.35	52.68	51.93	51.59
1995	53.80	54.83	61.34	55.46	55.62	58.75	61.79	56.86	54.22	56.58	57.04	57.06	54.32	54.61	52.48	52.53	54.62	51.53
1996	55.72	54.60	61.28	57.27	58.11	62.45	62.67	56.75	58.31	57.51	54.99	53.58	55.46	56.03	55.66	53.70	54.03	51.88
1997	55.32	55.18	58.50	59.45	56.89	59.47	61.30	56.20	57.63	56.56	54.01	52.51	54.94	55.21	55.82	55.58	55.61	49.72
1998	54.67	53.60	58.50	56.51	56.33	56.20	63.82	55.19	56.44	56.20	54.42	53.33	54.86	55.10	54.05	54.62	51.79	51.06
1999	55.71	56.08	58.02	57.63	56.67	57.31	64.79	57.93	56.16	58.08	55.70	54.21	55.67	56.22	55.23	53.94	52.79	52.62
2000	58.19	55.22	56.82	58.85	57.49	58.12	58.63	57.32	56.67	57.53	55.02	53.94	58.24	58.99	57.32	54.81	52.52	53.09
Ann Ave	55.39	56.71	56.73	58.04	59.10	59.48	60.78	58.41	58.50	57.34	56.27	54.59	54.95	55.33	55.89	54.25	53.44	52.71
Stdev	1.25	1.81	2.14	1.71	2.07	1.63	1.98	1.57	2.70	1.81	1.91	1.57	1.16	1.51	1.99	1.78	1.48	1.36
Max	58.19	61.77	61.34	61.41	63.16	63.59	64.79	62.29	64.46	61.09	60.41	57.96	58.24	58.99	60.92	57.62	56.06	55.58
Min	52.74	53.60	52.69	53.86	55.62	56.20	56.77	55.19	53.54	52.95	51.19	50.83	53.13	52.65	51.25	50.10	50.32	49.72
Max-Min	5.45	8.16	8.64	7.56	7.53	7.39	8.02	7.10	10.92	8.14	9.22	7.12	5.12	6.34	9.66	7.52	5.74	5.86

2.3.2 Lake Okeechobee Evapotranspiration

Although Lake Okeechobee (LOK) ET is predominantly open water ET, spatial variation is accounted for by conceptualizing the Lake as made up of three distinct zones (Figure 2.3.2.1): an open water zone, a marsh (wetted or inundated littoral) zone, and a no-water (dry littoral) zone. The surface areas of these zones vary with Lake stage. Lake Okeechobee ET computation was originally based on the pan evaporation method (Shih, 1980), expanded to take into consideration the no-water zone (Ahn and Ostrovsky, 1992), and improved to account for reference crop ET calculations based on first the Penman-Monteith method (Trimble, 1996) and later the SFWMD Simple Method (Irrizary, 2003). The following equation is used in the model on a daily basis:

$$ET_{LOK,t} = ET_{ref,t} [A_{w,t} + k (A_{m,t} + A_{n,t})] \quad (2.3.2.1)$$

where:

- $ET_{LOK,t}$ = total LOK evapotranspiration [ac-ft];
- k = evapotranspiration coefficient taken as 1.2 (Shih, 1980);
- $A_{w,t}$ = LOK open water surface area [acre];
- $A_{m,t}$ = LOK marsh surface area [acre];
- $A_{n,t}$ = LOK no-water surface area [acre]; and
- $ET_{ref,t}$ = wet marsh reference crop evapotranspiration [ft].

No-water zone ET is assumed to be limited by the total Lake monthly rainfall. Therefore, the total monthly dry littoral zone ET from the Lake cannot exceed the total monthly Lake rainfall. Daily dry littoral zone ET has a maximum value equal to the product of the total monthly Lake rainfall and the ratio of the daily pan evaporation to the total monthly pan evaporation.

The marsh zone exists where the bottom elevation of the Lake is above 11.5 ft National Geodetic Vertical Datum (NGVD) (Shih, 1980). The following conditional equations conceptualized in Figure 2.3.2.1 are used to calculate open water, marsh and no-water areas, respectively:

$$\begin{aligned} A_{w,t} &= fn(H_t) && \text{if } H_t \leq 11.5 \text{ ft NGVD} \\ &= A_{w,max} && \text{otherwise} \end{aligned} \quad (2.3.2.2)$$

$$\begin{aligned} A_{m,t} &= 0 && \text{if } H_t \leq 11.5 \text{ ft NGVD} \\ &= fn(H_t) - A_{w,max} && \text{otherwise} \end{aligned} \quad (2.3.2.3)$$

$$A_{n,t} = A_{LOK} - (A_{w,t} + A_{m,t}) \quad (2.3.2.4)$$

where:

- H_t = stage in Lake Okeechobee at time t [ft NGVD];
- $A_{w,max}$ = Lake Okeechobee open-water surface area at 11.5 ft NGVD or higher [acres];
- A_{LOK} = Lake Okeechobee surface area at 20 ft NGVD or higher (466,000 acres);
- $fn(H_t)$ = defines upper limit of area enclosed by the peripheral levee around the Lake; and
- $fn(H_t)$ = stage-area relationship for Lake Okeechobee, defined for stage less than or equal to 11.5 ft.

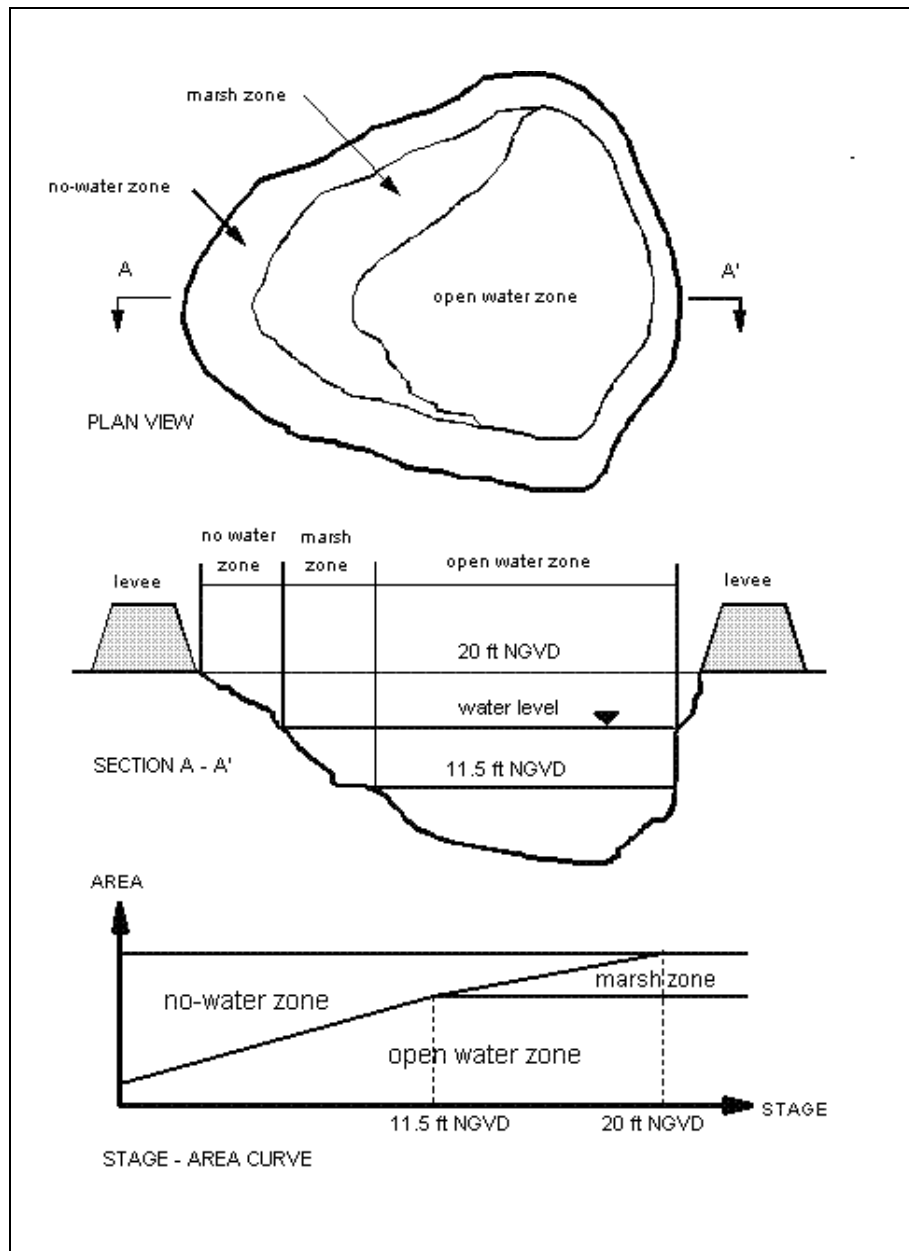


Figure 2.3.2.1 Conceptual Representation of the Different Lake Okeechobee Evapotranspiration Zones as Implemented in the South Florida Water Management Model

2.3.3 Everglades Agricultural Area

The calculation of ET in the EAA is strongly influenced by the operating rules governing the management of the EAA. The details of this topic will be discussed in Section 3.2. The remainder of the model domain, non-LOK and non-EAA, can be partitioned into non-irrigated and irrigated areas. The latter includes an unsaturated zone ET accounting procedure while the former makes simplifying assumptions for the unsaturated zone.

2.3.4 Non-irrigated Areas

Vegetation in the non-irrigated areas of the Lower East Coast (LEC) receives its water from rainfall and moisture from the unsaturated zone (or water table if the unsaturated zone dries up). For non-irrigated areas in the Water Conservation Areas (WCAs), Everglades National Park (ENP) and portions of Big Cypress National Preserve (BCNP), the following assumptions are made: (1) moisture content between land surface and water table does not change; (2) ET comes only from the saturated zone (ETS) and/or ponding (ETP); and (3) infiltration equals percolation.

The generalized form of the ET function in the model is:

$$ET = (KFACT) (ETR) \quad (2.3.4.1)$$

where:

ET = actual evapotranspiration;

KFACT = adjustment factor that takes into account vegetation/crop type and location of the water table relative to land surface as defined in Table 2.3.4.1 and Figure 2.3.4.1;

ETR = wet marsh potential ET (from Section 2.3.1).

Table 2.3.4.1 Variation of KFACT as a Function of Water Table Location

Zone	Depth from Land Surface to Water Level DWT: water table condition (below ground) PND: ponding condition (above ground)	Adjustment Factor, KFACT
I	$DWT \geq DDRZ$	0.0
II	$DSRZ < DWT < DDRZ$	$[(DDRZ - DWT) / (DDRZ - DSRZ)] (KVEG)$
III	$0 \leq DWT \leq DSRZ$	KVEG
IV	$0 < PND \leq OWPOND$	$KVEG + (KMAX - KVEG) (PND / OWPOND)$
V	$PND > OWPOND$	KMAX

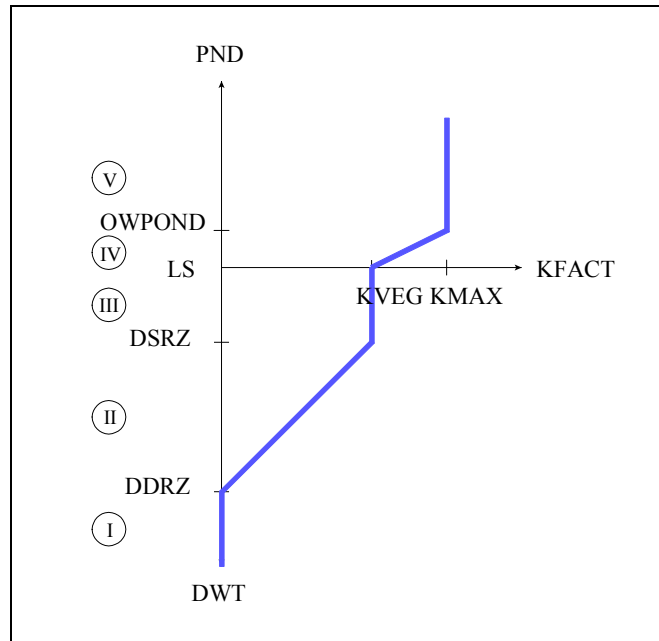


Figure 2.3.4.1 KFACT as a Function of Water Table Location

The definitions of the variables used in Figure 2.3.4.1 and Table 2.3.4.1 are as follows: *OWPOND* = minimum ponding depth above which ET for open-water is assumed, e.g., plants are fully submerged such that transpiration no longer contributes to ET; *LS* = land surface; *DSRZ* = depth from land surface to the bottom of the shallow root zone; *DDRZ* = depth from land surface to the bottom of the deep root zone; *PND* = depth from land to top of ponding; *DWT* = depth from land surface to water table; *KVEG* = calibrated vegetation/crop coefficient which is interpolated based on mid-month values assigned for each land use; *KMAX* = coefficient applied to ET for open water condition.

Tables 2.3.4.2 and 2.3.4.3 show the ET parameters associated with the modeled land cover/land use types as defined in Section 2.1. Note that:

1. Land uses 7 through 9, and 10 pertain to the three EAA agricultural types and Stormwater Treatment Area (STA) wetland classification, respectively.
2. Land uses 3-6, 12, 13 and 16 (McVoy and Park, 1997) can also be found in the Natural System Model (NSM) land use classification scheme.
3. The final or calibrated *KVEG* values for the three land uses in the EAA (land uses 7, 8 and 9 as shown in Table 2.3.4.3.) are the products of two parameters: (a) field-scale calibrated *KVEG*; and (b) calibration/adjustment factor *KCALIB* which are used to convert theoretical *KVEG* from field-scale to regional-scale. *KCALIB* values were determined during the calibration of the EAA (refer to Section 4.1).

For accounting purposes, if the water level goes above land surface (*LS*), the evapotranspiration is referred to as open-water ET (ETP). ETP is limited by the available ponding for the current day, i.e., previous day ponding plus current day rainfall. The portion of ET calculated from Equation (2.3.4.1) in excess of available ponding for the day is assumed to come from the saturated zone (ETS).

Table 2.3.4.2 Static Evapotranspiration Parameters used in the South Florida Water Management Model

	Land Use/Description	KMAX	OWPOND (ft)	DSRZ (ft)	DDRZ (ft)
1	Urban/low density	1.0	1.0	1.5	4.0
2	Agriculture/citrus	1.0	3.0	2.0	4.0
3	Wetland/freshwater marsh	1.0	4.0	0.0	1.2
4	Wetland/sawgrass plains	1.0	7.0	0.0	4.5
5	Wetland/wet prairie	1.0	3.5	0.0	2.0
6	Rangeland/shrubland (scrub and shrub)	1.0	3.5	0.0	7.0
7	Agriculture/row (or truck) crops	1.0	1.0	1.5	3.0
8	Agriculture/sugar cane	1.0	1.0	1.5	3.8
9	Agriculture/irrigated pasture	1.0	1.0	1.0	2.0
10	Wetland/stormwater treatment area and above-ground reservoir	1.0	4.0	0.5	5.0
11	Urban/high density	1.0	1.0	1.0	1.5
12	Forest/forested wetlands	1.0	10.0	0.0	9.0
13	Forest/mangroves	1.0	7.0	0.0	0.7
14	Forest/melaleuca	1.0	10.0	1.5	7.0
15	Wetland/cattail	1.0	6.0	0.0	3.0
16	Forest/forested uplands	1.0	10.0	4.8	11.0
17	Wetland/Ridge & Slough I	1.0	4.5	0.0	2.8
18	Wetland/marl prairie	1.0	3.0	0.0	6.5
19	Wetland/mixed cattail / sawgrass	1.0	7.0	0.0	4.0
20	Water/open water (deep excavated reservoirs)	1.0	0.0	0.0	0.0
21	Wetland/Ridge & Slough II	1.0	6.5	0.0	3.0
22	Wetland/Ridge & Slough III	1.0	3.0	0.0	1.5
23	Wetland/Ridge & Slough IV	1.0	6.8	0.0	3.0
24	Wetland/Ridge & Slough V	1.0	6.9	0.0	4.0
25	Urban/medium density urban	1.0	1.0	1.0	2.5

Notes: OWPOND is the minimum ponding depth above which ET for open-water is assumed.
DSRZ is the depth from the land surface to the bottom of the shallow root zone.
DDRZ is the depth from the land surface to the bottom of the deep root zone.

Table 2.3.4.3 Calibrated Vegetation/Crop Coefficient (KVEG) as a Function of Land Use and Month as Implemented in the South Florida Water Management Model

Land Use	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	0.546	0.512	0.534	0.542	0.552	0.572	0.638	0.706	0.705	0.676	0.604	0.562
2	0.701	0.693	0.610	0.542	0.661	0.710	0.744	0.810	0.822	0.772	0.723	0.700
3	0.780	0.750	0.800	0.830	0.850	0.900	0.940	0.970	0.970	0.902	0.840	0.800
4	0.830	0.800	0.840	0.870	0.890	0.900	0.910	0.960	0.960	0.880	0.860	0.840
5	0.780	0.750	0.790	0.800	0.810	0.830	0.850	0.880	0.880	0.835	0.810	0.790
6	0.820	0.790	0.830	0.840	0.850	0.860	0.870	0.880	0.880	0.850	0.835	0.820
7 ^a	0.640	0.690	0.870	0.950	0.860	0.660	0.610	0.660	0.710	0.870	0.930	0.880
8 ^a	0.800	0.600	0.550	0.800	0.950	1.000	1.050	1.050	1.050	1.000	0.950	0.900
9 ^a	0.650	0.700	0.750	0.950	0.950	0.980	0.980	0.980	0.940	0.800	0.870	0.650
10	0.830	0.782	0.810	0.835	0.848	0.860	0.880	0.920	0.920	0.872	0.844	0.830
11	0.413	0.381	0.392	0.401	0.412	0.422	0.435	0.455	0.480	0.483	0.442	0.415
12	0.700	0.670	0.710	0.720	0.740	0.750	0.770	0.780	0.780	0.760	0.730	0.710
13	0.710	0.700	0.730	0.750	0.790	0.830	0.890	0.950	0.950	0.870	0.790	0.730
14	0.770	0.740	0.790	0.820	0.850	0.880	0.900	0.930	0.930	0.850	0.810	0.780
15	0.805	0.780	0.810	0.820	0.832	0.848	0.862	0.890	0.890	0.840	0.815	0.807
16	0.730	0.700	0.740	0.760	0.800	0.870	0.940	0.980	0.980	0.950	0.870	0.750
17	0.760	0.740	0.770	0.790	0.810	0.850	0.920	0.980	0.980	0.910	0.810	0.770
18	0.780	0.750	0.790	0.820	0.850	0.890	0.960	0.995	0.995	0.950	0.860	0.800
19	0.815	0.790	0.825	0.835	0.850	0.870	0.882	0.930	0.930	0.860	0.835	0.820
20	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
21	0.610	0.600	0.630	0.650	0.670	0.690	0.720	0.740	0.740	0.720	0.675	0.620
22	0.780	0.750	0.790	0.800	0.820	0.850	0.870	0.880	0.880	0.870	0.840	0.820
23	0.770	0.750	0.780	0.800	0.830	0.860	0.910	0.960	0.960	0.910	0.840	0.780
24	0.830	0.800	0.840	0.870	0.890	0.900	0.910	0.960	0.960	0.880	0.860	0.840
25	0.500	0.450	0.475	0.490	0.510	0.530	0.560	0.600	0.600	0.570	0.540	0.510

^aFor the EAA, these values are multiplied by an additional calibration coefficient KCALIB (refer to Section 4.1).

2.3.5 Irrigated Areas in the Lower East Coast

For irrigated areas, primarily LEC Service Area grid cells, the unsaturated zone is treated as a separate control volume where infiltration, percolation, evapotranspiration and changes in soil moisture are accounted for. The reasons for the unsaturated zone accounting are: (1) the desire to implement the Water Shortage Plan in the LEC (SFWMD, 1991) which entails cutbacks in irrigation amounts and frequencies; (2) the need to quantify LEC irrigation applied to the unsaturated zone; and, consequently, (3) the need to more accurately assess changes in irrigation requirements associated with changes in land use.

In irrigated areas in the LEC, a two-step approach is taken to calculate total ET from each irrigated grid cell. In the first step, unsaturated zone moisture accounting is performed for the irrigated portion of a model grid cell. If ΔS represents the change in soil moisture content, then the water balance equation for the unsaturated zone at the end of each time step is:

$$\Delta S = \text{NIRRSUPTOT} - \text{ETU} + \text{INFILT} - \text{PERC} \quad (2.3.5.1)$$

where:

NIRRSUPTOT = total net irrigation application depth [in.];

ETU = evapotranspiration from the unsaturated zone [in.];

INFILT = total flux across land surface due to ponding/rainfall [in.]; and

PERC = total flux across the water table used as recharge to the saturated zone [in.].

NIRRSUPTOT and ETU represent the preprocessed (input to the model) total net irrigation supply and unsaturated zone evapotranspiration. They are calculated from the ET-Recharge model (Restrepo and Giddings, 1994) which is an extension of the Agricultural Field-Scale Irrigation Requirements Simulation (AFSIRS) program (Smajstrla, 1990) outlined in Appendix Q. Computational requirements, central processing unit (CPU) time and data storage for field-scale unsaturated zone moisture accounting are very prohibitive such that pre-processing ETU data was opted for the SFWMM.

Infiltration depth, INFILT, is the minimum of ponding depth, infiltration rate, and available unsaturated zone storage. Therefore, the time-dependent moisture content in the unsaturated zone (S_t) can be expressed as:

$$S_t = S_{t-1} + \text{INFILT} + \text{NIRRSUPTOT} - \text{ETU} \quad (2.3.5.2)$$

If S_t is less than the water-holding capacity of the unsaturated zone (SWSCAP), then percolation, PERC, is zero. Otherwise, PERC becomes the soil-moisture content in excess of SWSCAP and the final moisture-content for time step t equals SWSCAP.

In the second step, the saturated zone evapotranspiration (ETS) is calculated using ET from the generalized ET function, Equation (2.3.4.1):

$$\text{ETS} = \text{ET} - \text{ETU} \quad (2.3.5.3)$$

Due to differences in scale and assumptions used between the ET-Recharge model and SFWMM, there are instances when the unsaturated zone moisture accounting cannot be carried out due to the lack (or absence) of moisture in the unsaturated zone. In such cases, the unaccounted for ETU is taken directly out of the saturated zone, thus lowering the water table by a corresponding amount.

ET-Recharge Model

In the LEC service areas (Figure 1.3.5), irrigation supply and unsaturated zone ET are pre-processed, i.e., pre-calculated quantities input to SFWMM, and used in the unsaturated zone moisture accounting. These quantities, among others, were output from the ET-Recharge model (Giddings and Restrepo, 1995). This model was originally used to provide a more accurate method for estimating the recharge component for the District's countywide groundwater models. The model was later enhanced to handle any user-specified model grid, e.g., SFWMM grid system.

The necessary input to the model can be classified into the following two categories:

1. A text file description of basic element areas (BEAs): area; levels 1, 2, and 3 land use codes; soil code equivalent to AFSIRS SOIL.DAT file; cell (row and column numbers) location within the SFWMM grid system; vertical hydraulic conductivity of the soil; active/inactive designation for cell; flag indicating if the BEA is located east of the saltwater interface; and
2. A reference table for each BEA in (1) relating the District's level 3 land use classification (Florida Department of Transportation, 1985) to the following: runoff coefficients; crop type; growing season; percent pervious area; switch indicating if a BEA is irrigated or not; and water use type classification.

To perform a crop root zone water balance on a daily basis, the following approach is taken.

First, BEAs are defined for the LEC. By definition, a BEA is a polygon having a unique combination of attributes such as land use, soil type, percent irrigated, non-irrigated and impervious area, vertical hydraulic conductivity, and SFWMM cell location. As mentioned in Section 2.1.2, use of BEAs allows the SFWMM to capture land use variability at a scale smaller than the 2-mile by 2-mile discretization of the overall model grid. The size of a SFWMM grid cell is the upper limit on the size of a BEA.

Once defined, if a BEA falls within a pervious area, AFSIRS is called to perform crop root zone water balance on a daily basis. AFSIRS calculates irrigation requirements and crop evapotranspiration rates as a function of crop type, soil type, irrigation system, growing season, and climatic conditions. It assumes that crop requirements are met from the unsaturated zone through rainfall or supplemental irrigation. An irrigation management option within AFSIRS was selected such that the exact amount and timing of the irrigation is to be used to restore the root zone to field capacity (i.e., maximum yield and thus, maximum or potential ET is always maintained).

Some of the most important assumptions in AFSIRS as applied to the irrigated areas of the LEC are as follows:

1. The calculated drainage does not distinguish between runoff and percolation.
2. The crop root zone is entirely in the unsaturated zone.
3. Lateral flow is neglected in the unsaturated zone.
4. Crop requirements are met from the unsaturated zone through rainfall or supplemental irrigation.
5. Crop-water requirements are calculated based on maximum yield.
6. AFSIRS does not compute yield but calculates the quantity and frequency of irrigation necessary to avoid crop stress.
7. The calculated net irrigation requirement does not include leaching, freeze protection or crop cooling requirements.

Daily rainfall and wet marsh potential ET (ETR) are defined as inputs to AFSIRS. Since rainfall and ETR amounts are defined for each SFWMM grid cell, rainfall (RF) and ETR for a basic element area is taken as the value assigned to the SFWMM cell where the BEA is located. AFSIRS calculates the potential evapotranspiration for crop c (ET_c) using the formula:

$$ET_c = (k_c) (ETR) \quad (2.3.5.4)$$

where: k_c is the crop coefficient that varies with crop type and crop growth stage.

The rate at which water is returned from the soil to the atmosphere by ET is controlled by two factors: atmospheric demand and soil-water availability (Jensen, et al., 1990). At the end of each time step, the AFSIRS water balance equation for the crop root zone is:

$$\Delta STO = RAIN + NIRR - DRAIN0 - RUNOFF - ET \quad (2.3.5.5)$$

where:

ΔSTO = change in root zone soil water storage [in.];

RAIN = rainfall [in.];

NIRR = net irrigation requirement or irrigation supply [in.];

DRAIN0 = drainage [in.];

RUNOFF = surface runoff [in.]; and

ET = evapotranspiration [in.].

In the ET-Recharge model, the runoff and drainage terms are combined to form the variable DRAIN, i.e., $RUNOFF + DRAIN0$. All BEAs within a SFWMM grid cell can be combined and Equation (2.3.5.5) can be rearranged, and written in terms of NIRR (an input to the SFWMM):

$$NIRR = \Delta STO - RAIN + DRAIN + ET \quad (2.3.5.6)$$

Drainage is calculated as the difference between rainfall and available soil water storage (storage beyond field capacity) at the time rain occurs. By implementing an extended form of the Soil Conservation Service (SCS) runoff estimation method (McCuen, 1982), the DRAIN term can be partitioned back into total direct runoff and the original drainage term DRAIN0 in Equation 2.3.5.5 (Giddings and Restrepo, 1995). This approach involves the use of the Curve Number

(CN) for major storm events. AFSIRS assumes that the crop root zone is entirely within the unsaturated zone ($ET = ET_U$). The maximum unsaturated zone ET , ET_{Umax} , can vary depending on whether a BEA is impervious or pervious.

For impervious areas, the ET-Recharge model assumes negligible ET_{Umax} . For SFWMM grid cells with non-irrigated pervious areas, $ET_{Umax} = (ET_c)$ (% of pervious area). For SFWMM grid cells with irrigated pervious areas, $ET_{Umax} = (ET_c - \text{supplemental requirement})$ (% of pervious area), i.e., ET_{Umax} is limited by the amount of available soil moisture in the unsaturated zone. Supplemental irrigation requirements can be met from the water table.

The ET-Recharge model aggregates output from BEAs to SFWMM grid values. A list of output information generated on a daily basis from the model pertinent to the SFWMM is as follows (in inches per day):

1. composite crop PET per LEC model grid cell (ET_{p_cell});
2. unsaturated zone ET per LEC model grid cell (ET_{U_cell});
3. unsaturated zone ET for irrigated portion of each LEC model grid cell ($ETIU_{cell}$); and
4. irrigation deliveries per water use type (landscape, golf course, agricultural overhead, agricultural low volume, and agricultural other) for each LEC model grid cell.

A FORTRAN program is used to aggregate the irrigated (pervious) acreages for the BEAs into a composite acreage per LEC grid cell for each water use type. These acreages appear in the model as the independent terms LSC (landscape), GLF (golf course), AOH (agricultural overhead), ALV (agricultural low volume), and AOT (agricultural other).

Irrigation deliveries calculated from the ET-Recharge model are treated as target irrigation demands in the SFWMM. These irrigation demands can be met from the water table, wastewater reuse and public water supply (PWS), and are the basis for implementing the LEC trigger and cutback modules (refer to Table 3.5.4.1).

Irrigation Demands met by Alternate Sources

In the LEC, some areas may be irrigated by local municipal water (PWS pumpage) or wastewater reuse and do not rely on the surficial aquifer (water table). In order to account for the reduced impact of these acreages on the SFWMM grid cell water budget, a method was developed to reduce the irrigation demands that are met from the water table. This method identifies three parameters which represent the reduction in demands. These parameters are: FLI (fraction of landscape irrigation from PWS), FLR (fraction of landscape irrigation from wastewater reuse) and FGI (fraction of golf course irrigation from wastewater reuse). Values of FLI, FLR and FGI are defined as fractions of the total landscape (FLI and FLR) or golf course (FGI) irrigation and are subtracted from the total irrigation demands as calculated by the ET-Recharge model prior to influencing the SFWMM grid cell. Figures 2.3.5.1, 2.3.5.2 and 2.3.5.3 show the values used in the SFWMM for the FLI, FLR and FGI terms, respectively, for the 2000 condition. During drought conditions, the acreages whose irrigation demands are met by alternate sources will remain unaffected by water shortages and only the net water table demands (after reduction) will be cut back. For a more detailed description of this method, see Appendix S.

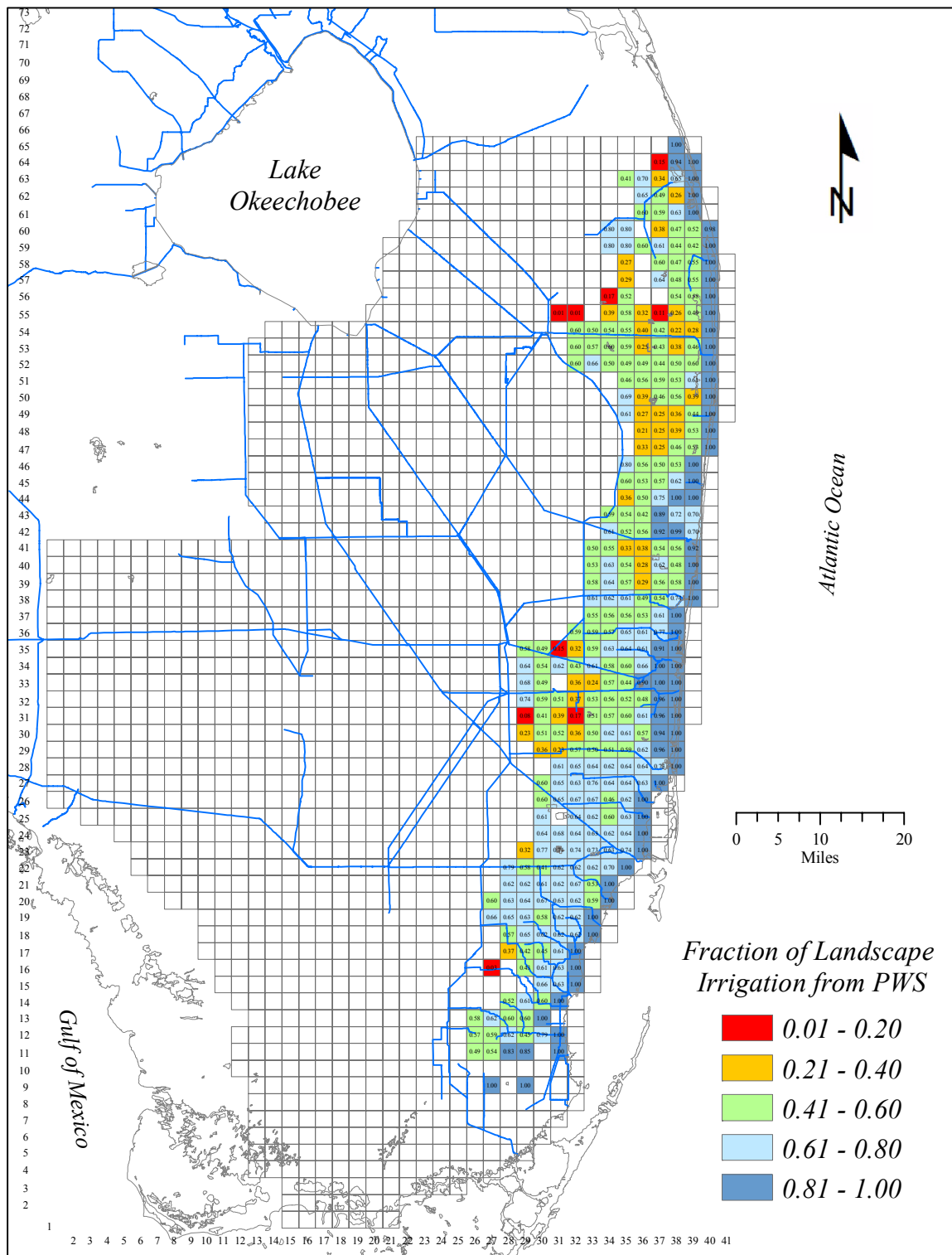


Figure 2.3.5.1 2000 Fraction of Landscape Irrigation from Public Water Supply Map

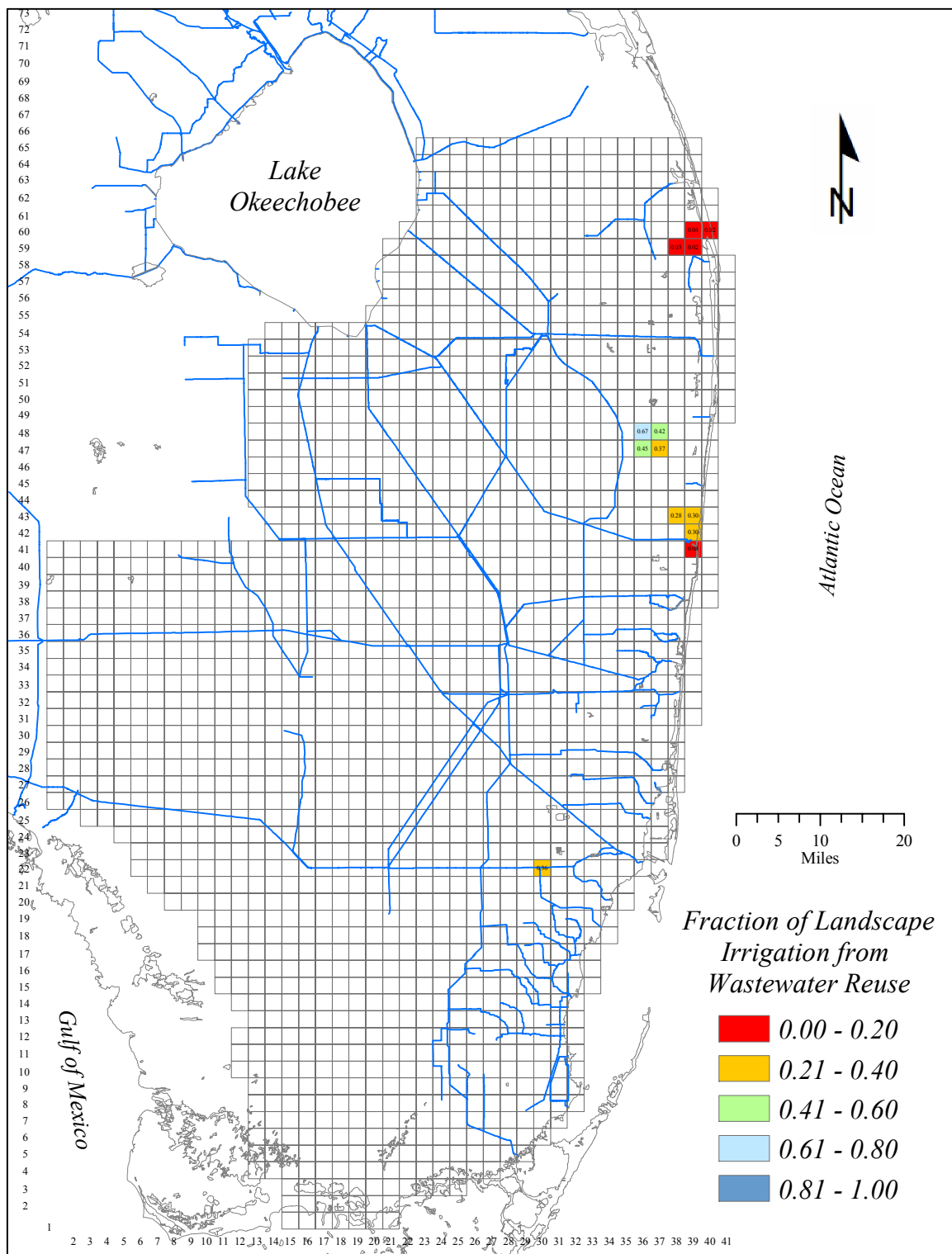


Figure 2.3.5.2 2000 Fraction of Landscape Irrigation from Wastewater Reuse Map

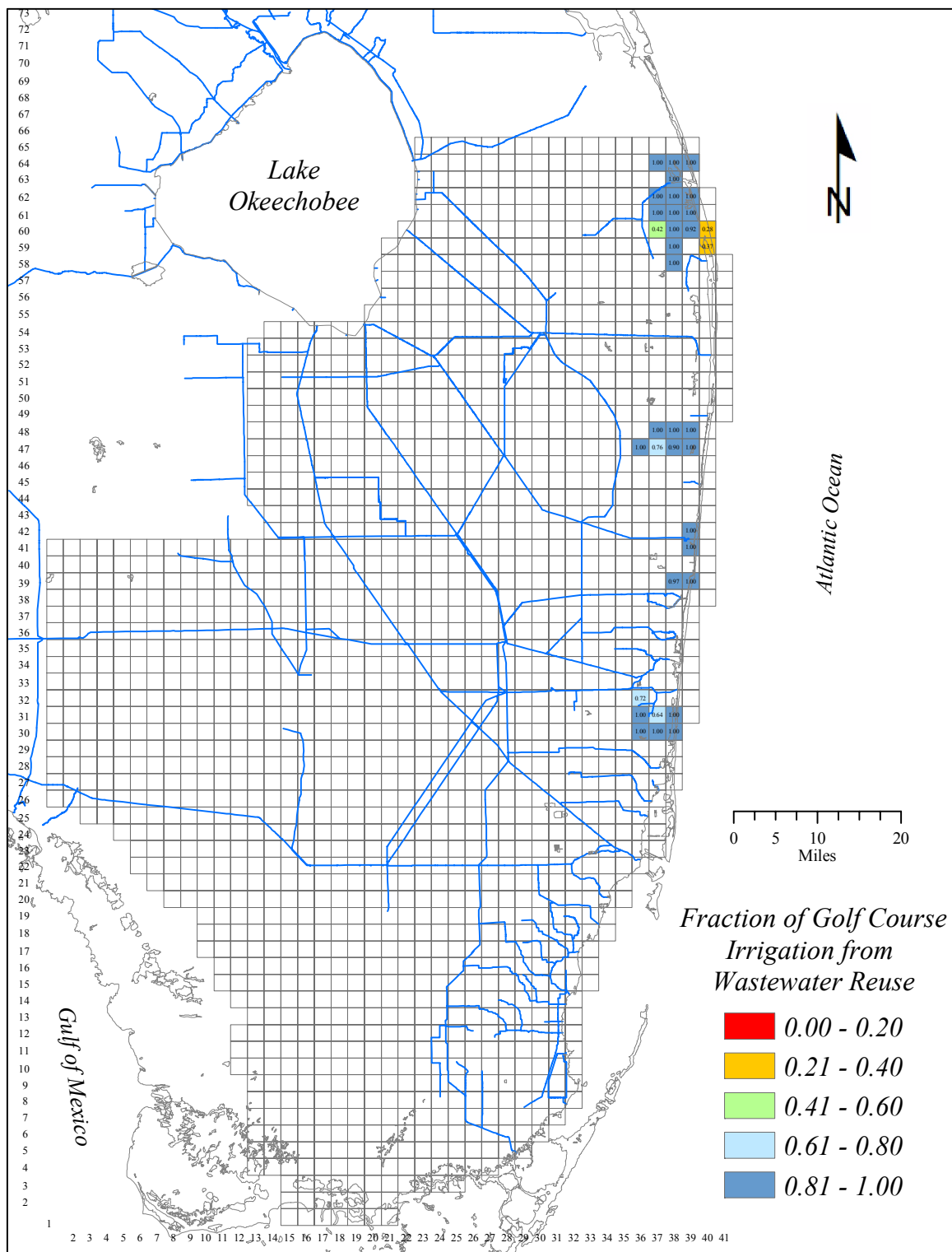


Figure 2.3.5.3 2000 Fraction of Golf Course Irrigation from Wastewater Reuse Map